

Gamma Dosimetry & Shielding++

J. Magill

Overview...

Biological Effects of Ionising Radiation

- Absorbed dose, Quality or Weighting Factor, Equivalent Dose

Attenuation of Gamma Radiation

- Calculation of the energy absorption, calculation of the equivalent dose rate, absorption in tissue, attenuation in shield materials, build-up factors

Nucleonica's Dosimetry & Shielding Module

The screenshot shows the Nucleonica web application interface for 'Dosimetry and Shielding++'. The header includes the Nucleonica logo and the tagline '... web driven nuclear science'. Below the header, there are navigation links: Applications, Data, Knowledge, My Preferences, Print, Networking, Nuclear Science, Help, and New Browser Tab. The main content area displays 'Co60' with its half-life (10.47 m, 5.27 y) and the title 'Dosimetry and Shielding++ 27 Cobalt'. A 'Current Chart: Karlsruhe' is indicated. The interface includes input fields for 'Element' (Co) and 'Mass' (60), a 'Mixture selector', and a checkbox for 'Include daughters'. The 'Dosimetry and Shielding' tab is active, showing a diagram of a radiation source (yellow radiation symbol) emitting rays through a 'Shield' (Pb) to a 'Detector'. The 'Initial source strength' is set to 'Activity(Bq)' with a value of '1E+06'. The 'Shielding material' is 'Pb' and the 'Dose rate (µSv/h)' is '2.67E-01'. The 'Source/detector distance (cm)' is '100'. The interface also has 'Start' and 'Reset' buttons.

Absorbed Dose

Usually the interaction of radiation with matter involves a transfer of energy from the radiation to the matter. Ultimately, the energy transferred either to tissue or to a radiation shield is dissipated as heat. The radiation dose depends on the intensity and energy of the radiation, the exposure time, the area exposed and the depth of energy deposition.

The modern SI unit of absorbed dose is the gray (Gy) where one gray is one joule per kilogram $1\text{Gy} = 1\text{ J kg}^{-1}$. In dosimetry, it is useful to define an average dose for a tissue or organ D_T . The absorbed dose to the mass δm_T , is defined as the imparted energy δE_T per unit mass of the tissue or organ, i.e.

$$D_T = \delta E_T / \delta m_T.$$

The absorbed dose rate is the rate at which an absorbed dose is received. The units are Gy s^{-1} , mGy hr^{-1} , etc.

Biological effects depend not only on the total dose to the tissue but also on the rate at which this dose was received. In organisms, mechanisms exist which enable molecules such as deoxyribonucleic acid (DNA) to recover if they have not been too badly damaged. Hence it is possible for organs to recover from a potentially lethal dose provided that the dose was supplied at a sufficiently slow rate. This phenomena is exploited in cancer radiotherapy

Quality or Weighting Factor

The biological effect of radiation is not just directly proportional to the energy deposited by radiation in an organism. It depends, in addition, on the way in which the energy is deposited along the path of the radiation, and this in turn depends on the type of radiation and its energy.

Thus for the same absorbed dose, the biological effect from high LET radiation such as α particles or neutrons is much greater than that from low LET radiation such as β or γ rays.

The quality or weighting factor, w_R , is introduced to account for this difference in the biological effects of different types of radiation. The weighting factors for the various types of radiation and energies is given in the table.

where $H_{T,R}$ is the equivalent dose in tissue T and w_R is the radiation weighting factor

The SI unit of dose is the Sievert, Sv (1 Sv = 1 J kg⁻¹, the old unit is the rem, 1 Sv = 100 rem). This is the equivalent dose arising from an absorbed dose of 1 Gy

Quality or weighting factors for different types of radiation

Radiation type	Radiation weighting factor, w_R
Photons	1
Electrons ^a and muons	1
Protons and charged pions	2
Alpha particles, fission fragments, heavy ions	20
Neutrons	A continuous function of neutron energy See Radiation weighting factors
All values relate to the radiation incident on the body or, for internal radiation sources, emitted from the incorporated radionuclide(s).	
^a Note the special issue of Auger electrons discussed in ICRP 103 (2007).	

$$H_{T,R} = w_R \cdot D_{T,R} ,$$

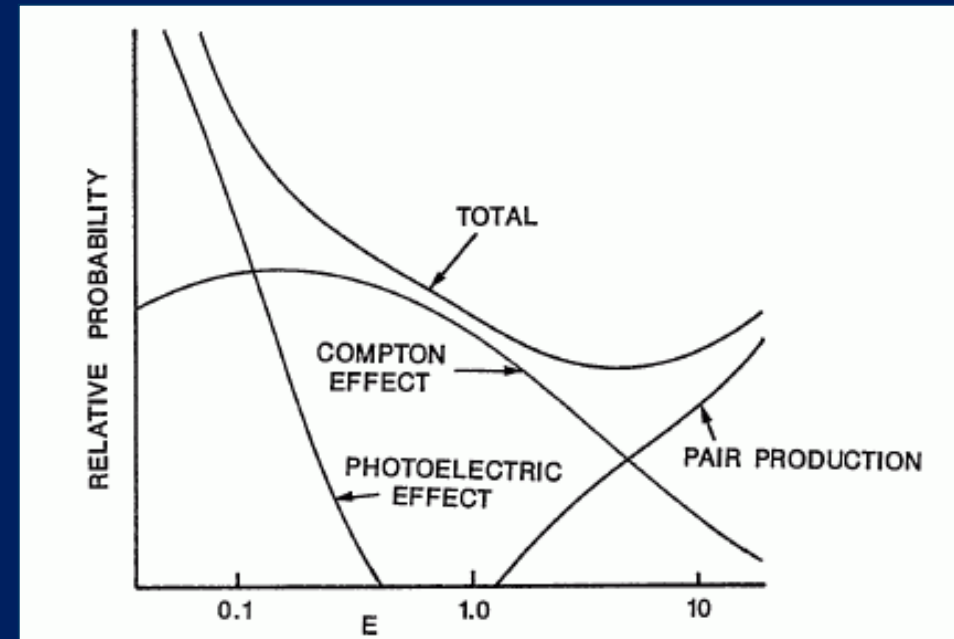
Attenuation of Gamma Radiation

The attenuation coefficient discussed above is a measure of how photons are removed from the beam under conditions of good geometry. Attenuation is a result of three basic processes: the photoelectric effect (pe), Compton scattering (cs), and pair production (pp) and the total attenuation coefficient is a sum of the attenuation coefficients for these processes.

$$\mu = \mu_{pe} + \mu_{cs} + \mu_{pp}$$

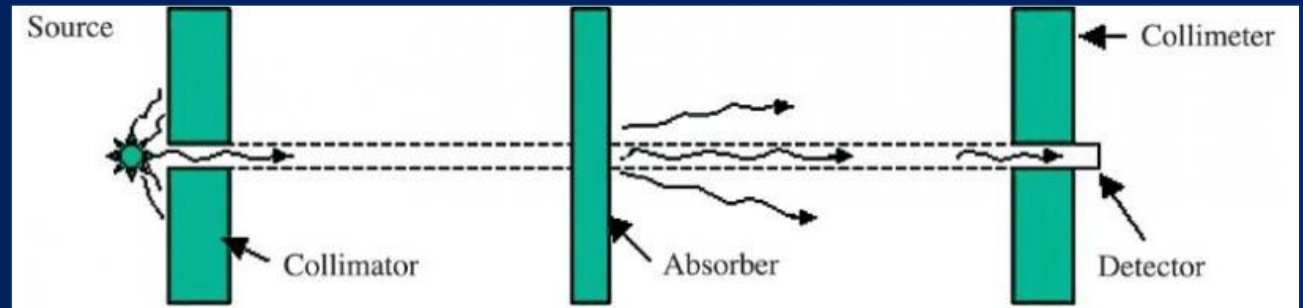
The total attenuation coefficient μ given above is the fraction of the energy of the beam that is removed per unit distance in the medium. The energy absorbed in the medium is determined by the energy absorption coefficient μ_{en} . The difference between μ and μ_{en} results from the fact that energy may be lost from the medium through Compton scattering and by annihilation radiation.

- For dose calculations in tissue for example, the energy absorption coefficient μ_{en} must be used.
- For shielding calculations, the attenuation coefficient should be used.



Attenuation of Gamma Radiation

Gamma radiation cannot be completely absorbed, but only reduced in intensity, when passing through matter. If mono-energetic gamma radiation attenuation measurements are made under conditions of good geometry, i.e. with a well-collimated, narrow beam of radiation, a straight-line relationship between the logarithm of the intensity versus the thickness d of the shield is obtained.

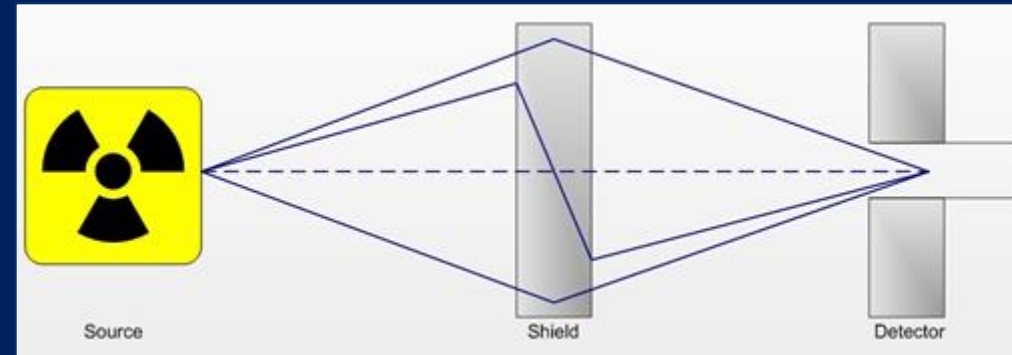


$$\frac{I}{I_0} = e^{-\mu d}$$

$$I = I_0 \cdot e^{-(\mu_t / \rho) \cdot (\rho d)}$$

However, under conditions of poor geometry, i.e. for a broad beam or for a very thick shield, the above relation underestimates the required shield thickness. It assumes that every photon that interacts with the shield will be removed from the beam and thus will not be available for counting in the detector. Under conditions of poor geometry, as shown in Figure, this assumption is not valid; a significant number of photons may be scattered by the shield into the detector, or photons that had been scattered out of the beam may be scattered back in after a second collision.

The shield thickness for conditions of poor geometry may be estimated by modification of the basic attenuation relation given above through the use of a build-up factor B, i.e.



Gamma radiation attenuation under conditions of broad beam geometry showing the effect of photons scattered into the detector

$$I = B \cdot I_0 \cdot e^{-(\mu_t / \rho) \cdot (\rho x)}$$

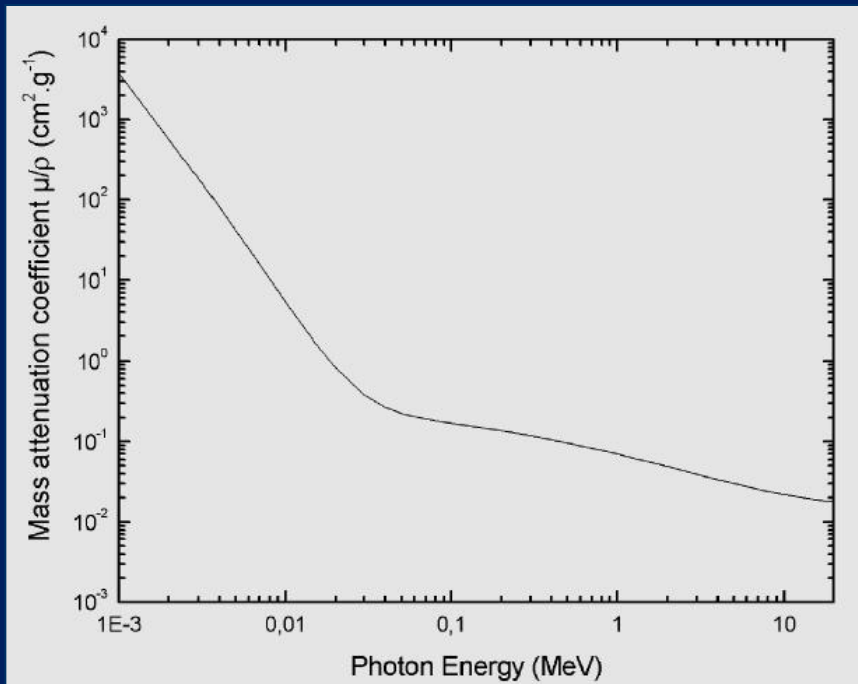
Calculation of the Equivalent Dose Rate

$$\frac{dH}{dt} (Sv/h) = (5.77 \cdot 10^{-4}) \cdot A / (4\pi R^2) \cdot \sum_i E_i (keV) \cdot P_i \cdot B_i \cdot e^{-(\mu_l/\rho)_i^{shield} \cdot (\rho d)} (\mu_l/\rho)_i^{tis}$$

$$\frac{dH}{dt}(Sv/h) = (5.77 \cdot 10^{-4}) \cdot A / (4\pi R^2) \cdot \sum_i E_i(keV) \cdot P_i \cdot B_i \cdot e^{-(\mu_l/\rho)_i^{shield} \cdot (\rho d)} (\mu_l/\rho)_i^{tis}$$

Absorption in Tissue

The dependence of $(\mu/\rho)_{tis}$ on energy is shown in Fig. 1. This data has been taken from the NIST database. In the calculations, a linear interpolation is carried out (actually the linear interpolation is carried out on the log (mass-absorption coefficient) vs. log(energy) plot). For energies lower than the minimum energy (0.001 MeV), an extrapolation is performed.



Mass absorption coefficient for tissue

Energy (MeV)	$(\mu/\rho)_{tis}$ (cm ² g ⁻¹)	Energy (MeV)	$(\mu/\rho)_{tis}$ (cm ² g ⁻¹)	Energy (MeV)	$(\mu/\rho)_{tis}$ (cm ² g ⁻¹)
1.00E-03	3.70E+03	8.00E-03	9.94E+00	6.00E-01	3.25E-02
1.04E-03	3.38E+03	1.00E-02	4.99E+00	8.00E-01	3.18E-02
1.07E-03	3.08E+03	1.50E-02	1.40E+00	1.00E+00	3.07E-02
1.50E-03	1.25E+03	2.00E-02	5.66E-01	1.25E+00	2.94E-02
2.00E-03	5.58E+02	3.00E-02	1.62E-01	1.50E+00	2.81E-02
2.15E-03	4.57E+02	4.00E-02	7.22E-02	2.00E+00	2.58E-02
2.30E-03	3.78E+02	5.00E-02	4.36E-02	3.00E+00	2.26E-02
2.47E-03	3.09E+02	6.00E-02	3.26E-02	4.00E+00	2.05E-02
2.64E-03	2.59E+02	8.00E-02	2.62E-02	5.00E+00	1.90E-02
2.82E-03	2.14E+02	1.00E-01	2.55E-02	6.00E+00	1.79E-02
3.00E-03	1.82E+02	1.50E-01	2.75E-02	8.00E+00	1.64E-02
3.61E-03	1.06E+02	2.00E-01	2.94E-02	1.00E+01	1.55E-02
4.00E-03	8.03E+01	3.00E-01	3.16E-02	1.50E+01	1.42E-02
5.00E-03	4.14E+01	4.00E-01	3.25E-02	2.00E+01	1.36E-02
6.00E-03	2.39E+01	5.00E-01	3.27E-02		

Table of mass absorption coefficients for tissue

Nucleonica's Dosimetry & Shielding Module

The Dosimetry and Shielding in Nucleonica allows the user to calculate gamma dose rates from point sources of single nuclides and nuclide mixtures. The user interface is shown in figure.

The main tab allows the user to select the nuclide source strength, source / detector distance, shield material and material thickness.

The screenshot displays the Nucleonica web application interface for the Dosimetry and Shielding++ module. The header features the Nucleonica logo and the tagline "... web driven nuclear science". A navigation bar includes links for Applications, Data, Knowledge, My Preferences, Print, Networking, Nuclear Science, Help, and New Browser.

The main content area is titled "Dosimetry and Shielding++" and "27 Cobalt". A small chart for Co60 shows half-life values of 10.47 m and 5.27 y. Below this, the "Current Chart: Karlsruhe" is indicated.

The interface includes input fields for "Element" (Co) and "Mass" (60), a "Mixture selector" button, and a checkbox for "Include daughters". The "Dosimetry and Shielding" tab is active, with sub-tabs for "Dose rate/Thickness graph", "Options", and "Mixture details".

The main calculation area contains the following inputs and visual elements:

- Initial source strength:** Activity(Bq) dropdown set to 1E+06.
- Shielding material:** Pb dropdown, with a thickness input of 1 cm.
- Dose rate ($\mu\text{Sv/h}$):** Displayed as ???.
- Diagram:** A schematic showing a radiation source (yellow square with a black radiation symbol) emitting rays through a shield (grey rectangle) to a detector (grey rectangle). The source is labeled "Source", the shield is labeled "Shield", and the detector is labeled "Detector".
- Source/detector distance (cm):** A horizontal double-headed arrow indicates a distance of 100 cm.
- Buttons:** "Start" and "Reset" buttons are located at the bottom of the diagram area.

Results for 1MBq Co-60 with 1cm Pb shielding

Dosimetry and Shielding

Dose rate/Thickness graph Options Mixture details

Source strength

Activity(Bq) 1.0000e+6

Shielding material Pb 1 cm

Dose rate ($\mu\text{Sv/h}$) 2.67E-01

Source

Shield

Detector

Source/detector distance (cm) 100

Start Reset

Show details...

☒ Show radiation details

Nuclide	Gamma Energy (keV)	Emission Probability P (per disintegration)	Mass Attenuation Coefficient (shielding)(cm^2/g)	Number of Mean Free Paths ($\mu\text{-d}$)	Build-up Factor	Mass Absorption Coefficient (tissue)(cm^2/g)	Tissue γ Dose Rate($\mu\text{Sv/h}$)	γ Exposure Rate($\mu\text{Gy/h}$)
27 Co 60	1332.49	1	0.0564	0.64	1.53E+00	0.0289	0.143	0.131
27 Co 60	1173.23	0.999	0.062	0.704	1.57E+00	0.0298	0.125	0.117
27 Co 60	826.1	7.6E-05	0.0859	0.975	1.69E+00	0.0316	5.83E-06	5.31E-06
27 Co 60	2158.57	1.2E-05	0.0454				2.66E-06	2.48E-06
27 Co 60	347.14	7.5E-05	0.305				2.18E-07	1.95E-07
27 Co 60	2505.69	2E-08	0.0439				4.97E-09	4.83E-09
27 Co 60	7.47815	6.44E-05	271				0	0
27 Co 60	7.46089	3.27E-05	272	3090	1	12.3	0	0
27 Co 60	8.26	1.31E-05	211	2400	1	9.01	0	0
27 Co 60	0.85	1.49E-06	7160	81200	1	5380	0	0

A list of all energy lines and emission probabilities used in the calculation are given

Summary table...

Half-Value Shield Thickness(cm)	2.02E+00
Tenth-Value Shield Thickness(cm)	5.03E+00
Equivalent Dose Rate Constant $\Gamma(\text{mSv}\cdot\text{m}^2/\text{GBq}\cdot\text{h})$	3.37E-01
Tissue Gamma Dose Rate ($\mu\text{Sv/h}$)	2.67E-01
Exposure Rate ($\mu\text{Gy/h}$)	2.48E-01
Effective Build-up factor	1.55E+00
Effective Number of Mean Free Paths ($\mu\text{-d}$)	6.70E-01

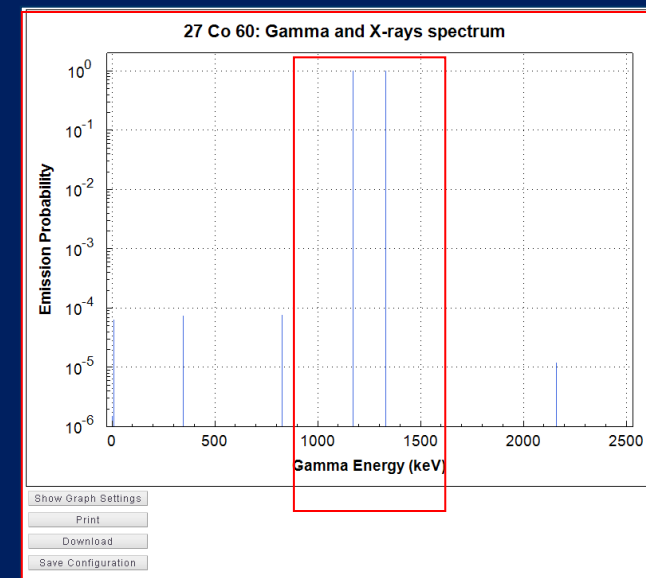
half- and tenth-value thicknesses of shield material and the specific gamma dose rate constant.

Download Excel CSV Separator: Semicolon (";") Use field qualifier ("")

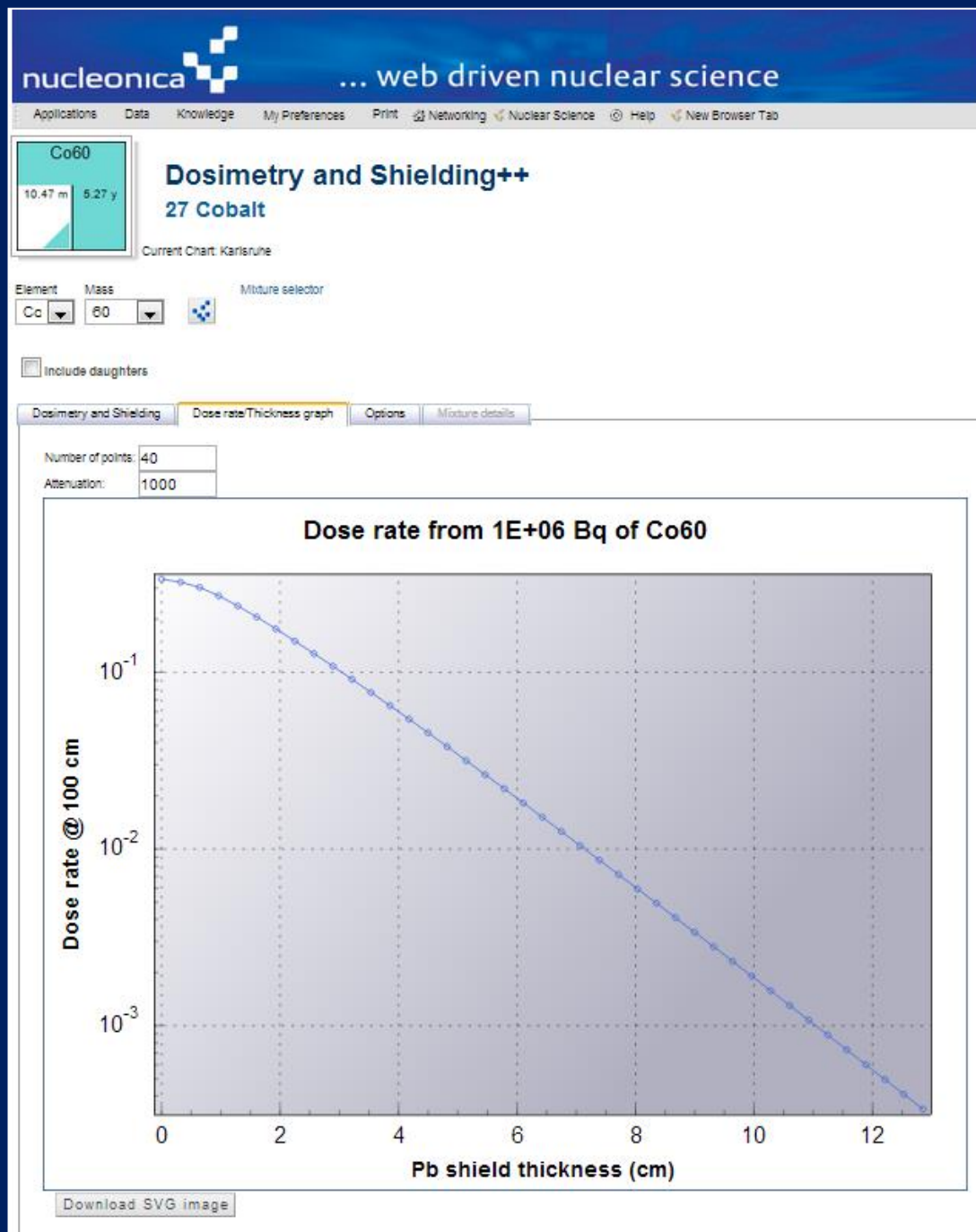
Number of lines (γ):	6	$\Sigma\text{E.P.}(\gamma)$:	2.50E+06
Number of lines (X):	4	$\Sigma\text{E.P.}(X)$:	8.35E-01
Number of lines ($\gamma+X$):	10	$\Sigma\text{E.P.}(\text{total})$:	2.50E+06

Subsidiary quantities used in the calculations, such as the absorption coefficient, number of mean free path in the shield material, and the build-up factor for each energy line are given.

Gamma spectrum...



Dose Rate / Thickness Tab



Options Tab:

In the Energy range option, the user can choose to include only gammas, X-rays, or both in the calculation. In addition the user can set the minimum (threshold) energy of gamma and X-rays to be included in the calculation. The default value is 15 keV – photons with lower energy are absorbed by the outer layers of human tissue.

A new feature is the total gamma dose rate. Here the user can enter the exposure time.

The screenshot shows the 'Dosimetry and Shielding++' software interface. At the top left, there is a box for 'Co60' with a half-life diagram showing 10.47 m and 5.27 y. To the right, the title 'Dosimetry and Shielding++' and '27 Cobalt' are displayed. Below this, it says 'Current Chart: Karlsruhe'. The main interface has a top bar with four tabs: 'Dosimetry and Shielding', 'Dose rate/Thickness graph', 'Options' (which is selected), and 'Mixture details'. Below the tabs is a section titled 'Dosimetry and Shielding Settings'. This section contains two columns of settings. The left column, 'Energy range option:', includes radio buttons for 'Only Gamma', 'Only X-rays', and 'Gamma and X-rays' (which is selected), a checked checkbox for 'Threshold set', a text input for 'Threshold energy (keV)' with the value '15', a text input for 'Accuracy factor' with the value '0.01', a checked checkbox for 'Total Gamma Dose', a text input for 'Exposure time' with the value '4', and a dropdown menu for units set to 'Hours'. The right column, 'Mode of operation option:', includes radio buttons for 'Gamma Dose Rate' (selected), 'Shield Thickness', and 'Source Strength'. At the bottom, there is a 'Result Detail option:' with a checked checkbox for 'Show Nuclides'.

Co60
10.47 m 5.27 y

Dosimetry and Shielding++

27 Cobalt

Current Chart: Karlsruhe

Element Mass Mixture selector
Co 60

☐ Include daughters

Dosimetry and Shielding Dose rate/Thickness graph **Options** Mixture details

Dosimetry and Shielding Settings

Energy range option:

- ☐ Only Gamma
- ☐ Only X-rays
- ☒ Gamma and X-rays

☒ Threshold set

Threshold energy (keV): 15

Accuracy factor: 0.01

☒ Total Gamma Dose

Exposure time: 4 Hours

Result Detail option: ☒ Show Nuclides

Mode of operation option:

- ☒ Gamma Dose Rate
- ☐ Shield Thickness
- ☐ Source Strength

- Calculation of the dose rate for a given shield material and thickness.

- Calculation of the thickness of shield material required to obtain a given dose rate

- Obtain the source strength when the dose rate, shield material and thickness are known

Co60
10.47 m 5.27 y
Current Chart: Karlsruhe

Element: Co Mass: 60 Mixture selector

☐ Include daughters

Dosimetry and Shielding Dose rate/Thickness graph Options Mixture details

Initial source strength: Activity(Bq) 1E+06

Shielding material: Pb 1 cm

Dose rate (μSv/h): ???

Source/detector distance (cm): 100

Co60
10.47 m 5.27 y
Current Chart: Karlsruhe

Element: Co Mass: 60 Mixture selector

☐ Include daughters

Dosimetry and Shielding Dose rate/Thickness graph Options Mixture details

Initial source strength: Activity(Bq) ???

Shielding material: Pb ??? cm

Dose rate (μSv/h): 2.67E-01

Source/detector distance (cm): 100

Co60
10.47 m 5.27 y
Current Chart: Karlsruhe

Element: Co Mass: 60 Mixture selector

☐ Include daughters

Dosimetry and Shielding Dose rate/Thickness graph Options Mixture details

Initial source strength: Activity(Bq) 1E+06

Shielding material: Pb ??? cm

Dose rate (μSv/h): 2.67E-01

Source/detector distance (cm): 100

The importance of including daughters:

example: Cs137

Cs137
30.06 y

Dosimetry and Shielding++

55 Cesium

Current Chart: Karlsruhe

Element: Cs Mass: 137 Mixture selector

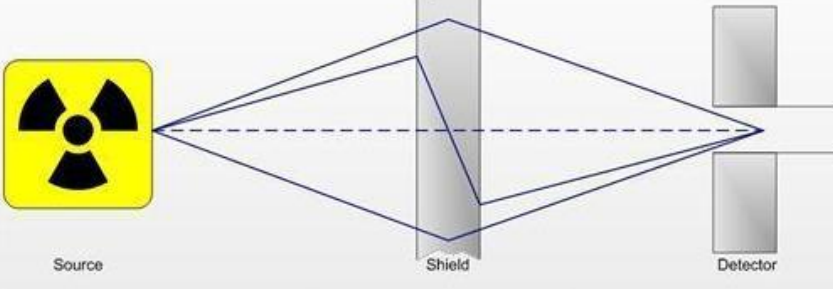
☐ Include daughters

Dosimetry and Shielding | Dose rate/Thickness graph | Options | Mixture details

Initial source strength: Activity(Bq) 1.00e+6

Shielding material: Pb 1 cm

Dose rate ($\mu\text{Sv/h}$) **2.31E-09**



Source/detector distance (cm) 100

Cs137
30.06 y

Dosimetry and Shielding++

55 Cesium

Current Chart: Karlsruhe

Element: Cs Mass: 137 Mixture selector

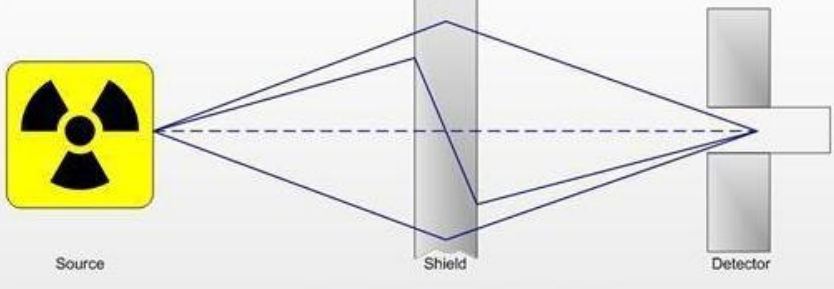
☒ Include daughters "Cooling" time 10 Minutes

Dosimetry and Shielding | Dose rate/Thickness graph | Options | Mixture details

Initial source strength: Activity(Bq) 1.00e+6

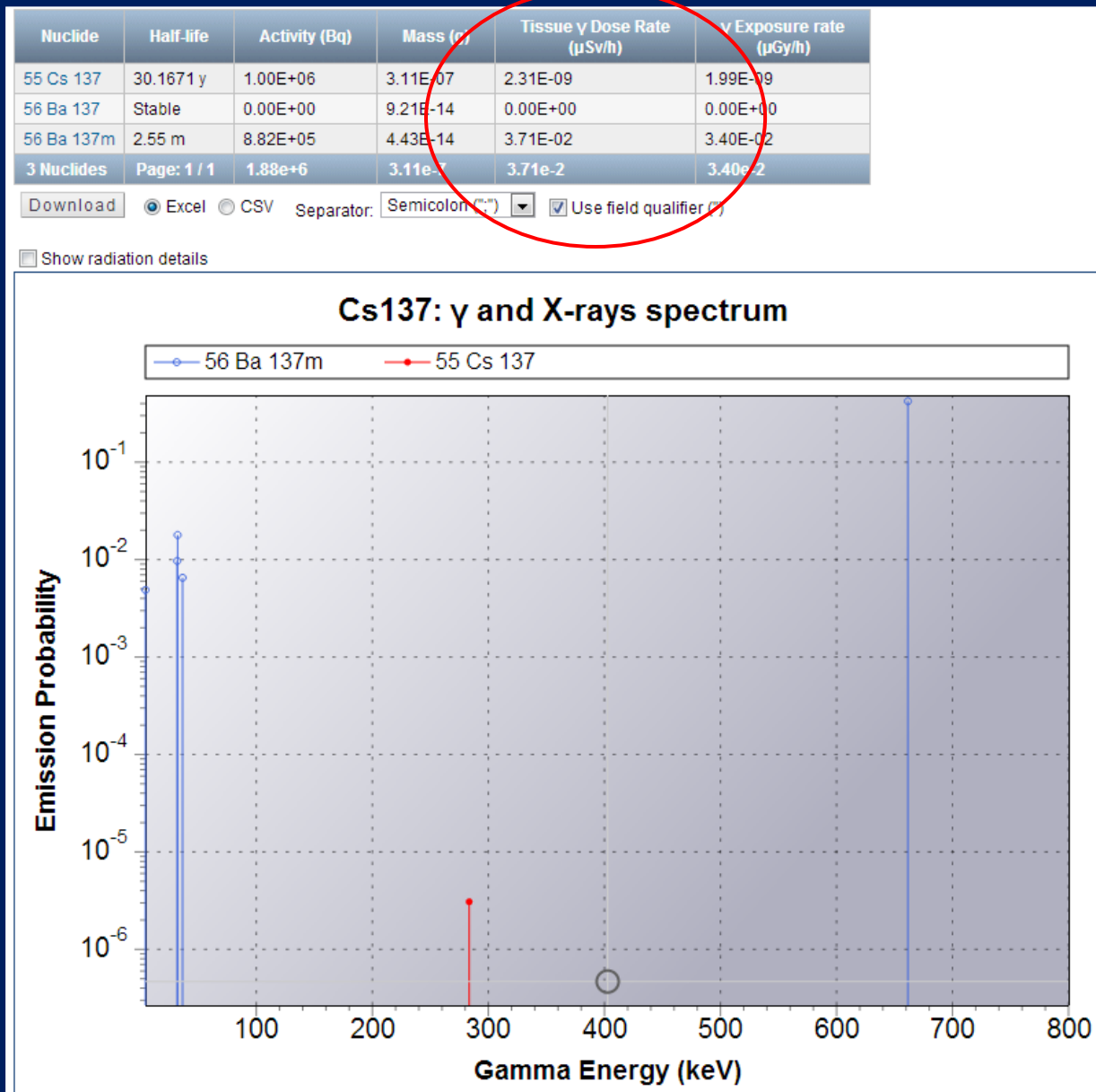
Shielding material: Pb 1 cm

Dose rate ($\mu\text{Sv/h}$) **3.71E-02**



Source/detector distance (cm) 100

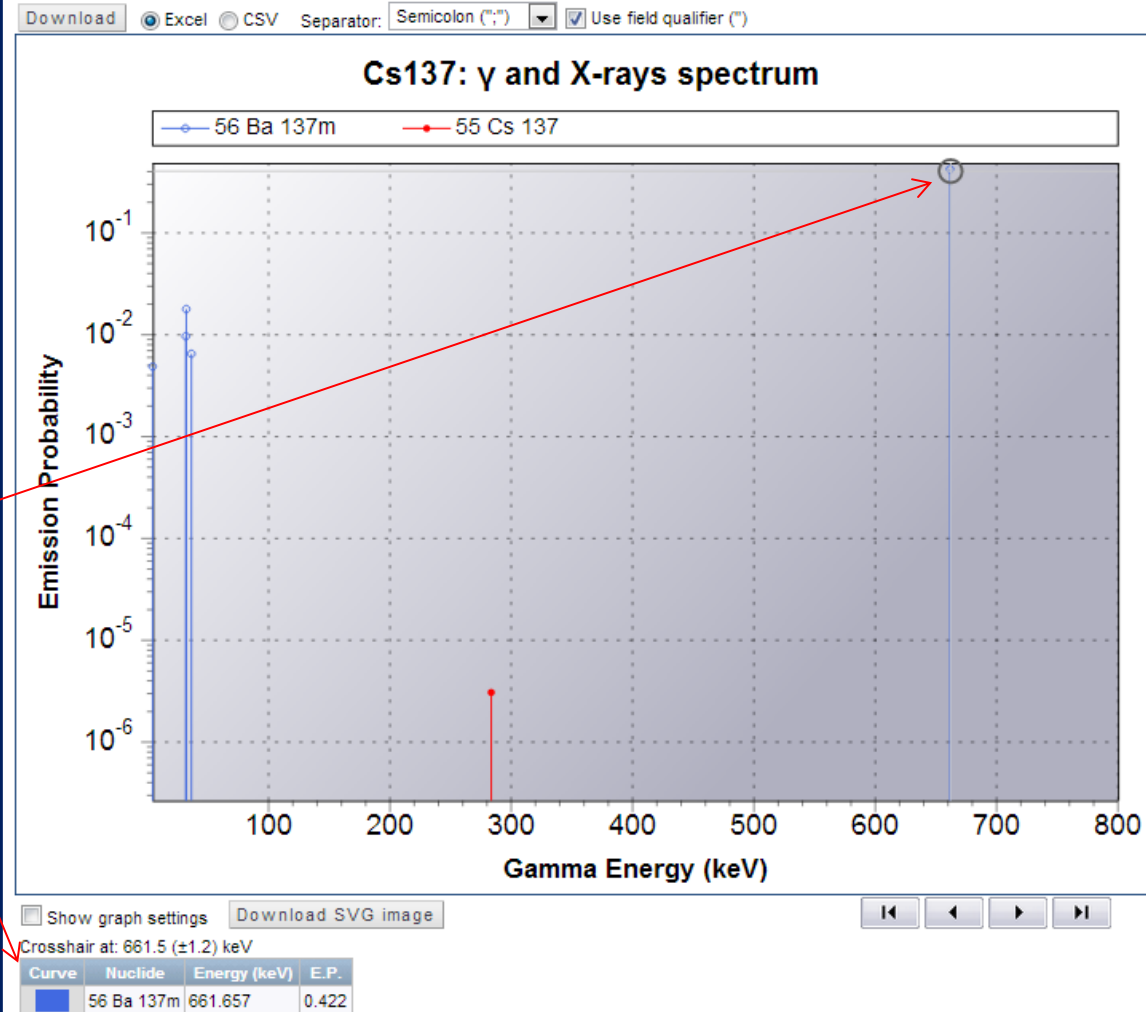
Ba137m has a half-life of 2.55 min. Even after 10 mins, the Ba137m is the main dose contributor!



Cs137 lines are negligible....

☒ Show radiation details

Nuclide	Gamma Energy (keV)	Emission Probability (per disintegration)	Mass Attenuation Coefficient (shielding)(cm ² /g)	Number of Mean Free Paths (μ·d)	Build-up Factor	Mass Absorption Coefficient (tissue)(cm ² /g)	Tissue γ Dose Rate(μSv/h)
55 Cs 137	283.5	3.08E-06	4.57E-01	5.19E+00	1.76E+00	3.13E-02	2.31E-09
56 Ba 137m	661.657	4.22E-01	1.11E-01	1.26E+00	1.69E+00	3.23E-02	3.71E-02
56 Ba 137m	32.1936	1.79E-02	2.52E+01	2.87E+02	1.03E+00	1.33E-01	0.00E+00
56 Ba 137m	31.8171	9.69E-03	2.60E+01	2.95E+02	1.03E+00	1.37E-01	0.00E+00
56 Ba 137m	36.4	6.50E-03	1.84E+01	2.09E+02	1.04E+00	9.41E-02	0.00E+00
56 Ba 137m	4.47	4.88E-03	9.56E+02	1.09E+04	1.00E+00	5.77E+01	0.00E+00
6	Page: 1 / 1						3.71e-2



Mixtures: Example natural uranium at t=0

nucleonica ... web driven nuclear

Applications Data Knowledge My Preferences Print Networking Nuclear Science

Dosimetry and Shielding++
Natural Uranium

Mixture: Natural Uranium Nuclide selector

☐ Include daughters

Dosimetry and Shielding Dose rate/Thickness graph Options Mixture details

Initial source strength: Mass(g) 238.0

Shielding material: Pb 0 cm

Dose rate ($\mu\text{Sv/h}$): 2.92E-03

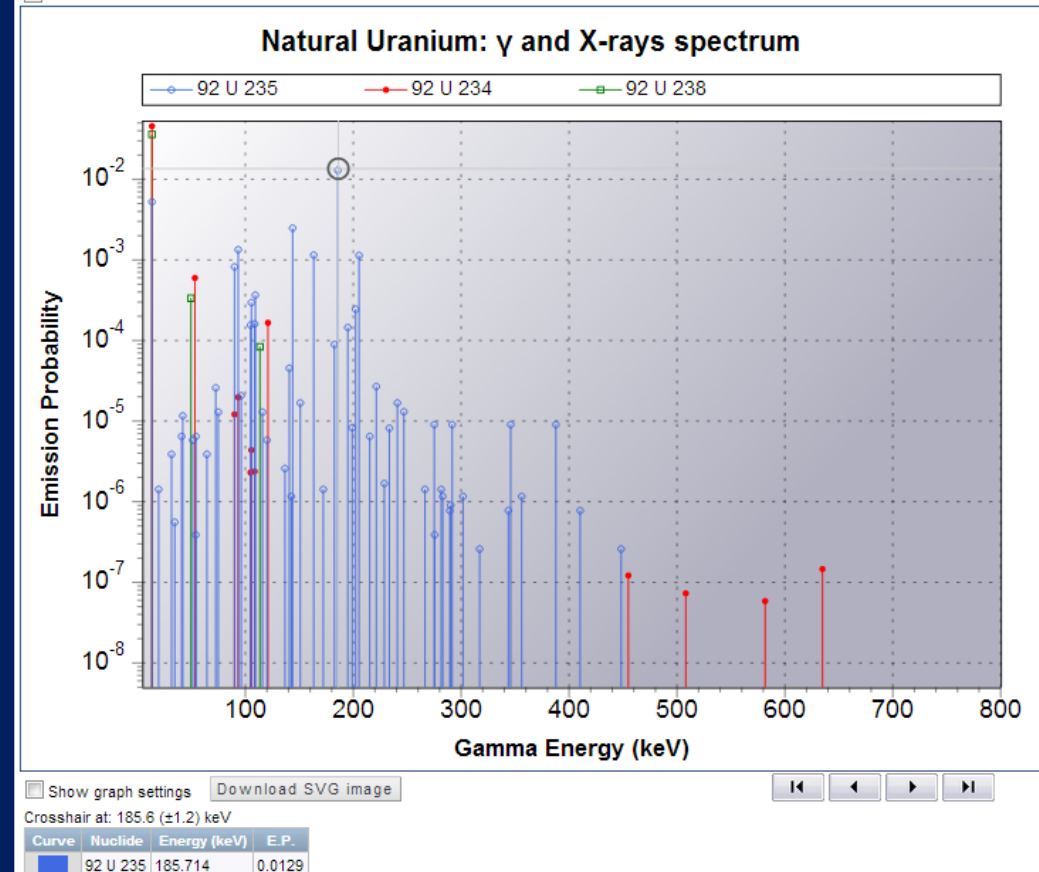
Source/detector distance (cm): 100

At t=0: no daughters


Nuclide	Half-life	Activity (Bq)	Mass (g)	Tissue γ Dose Rate ($\mu\text{Sv/h}$)	γ Exposure rate ($\mu\text{Gy/h}$)
92 U 234	245.5 ky	2.91E+06	1.26E-02	5.20E-05	4.97E-05
92 U 235	704 My	1.35E+05	1.69E+00	2.84E-03	2.49E-03
92 U 238	4.468 Gy	2.94E+06	2.36E+02	2.70E-05	5.02E-05
3 Nuclides	Page: 1 / 1	5.99E+6	2.38E+2	2.92E-3	2.59E-3

Download ☒ Excel ☐ CSV Separator: Semicolon (";",) ☒ Use field qualifier ("")

☐ Show radiation details



Mixtures: Example natural uranium at t=100y



Dosimetry and Shielding++

Natural Uranium

Mixture: Natural Uranium Nuclide selector

☒ Include daughters
 Cooling time: 100 Years

Dosimetry and Shielding
Dose rate/Thickness graph
Options
Mixture details

Initial source strength

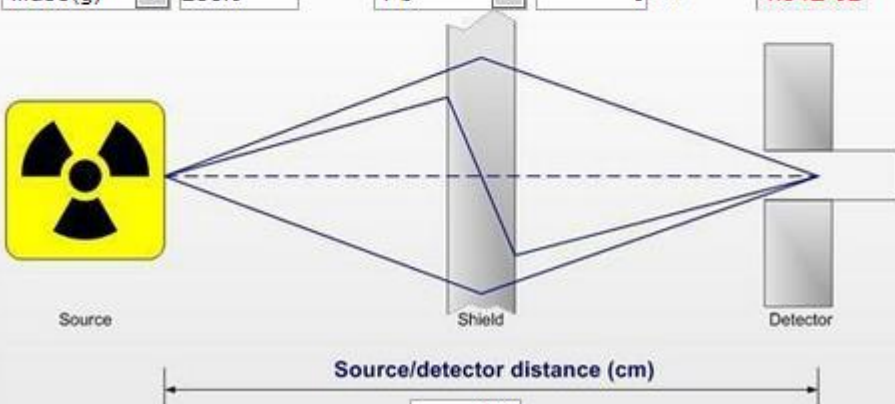
Mass(g) 238.0

Shielding material

Pb 0 cm

Dose rate ($\mu\text{Sv/h}$)

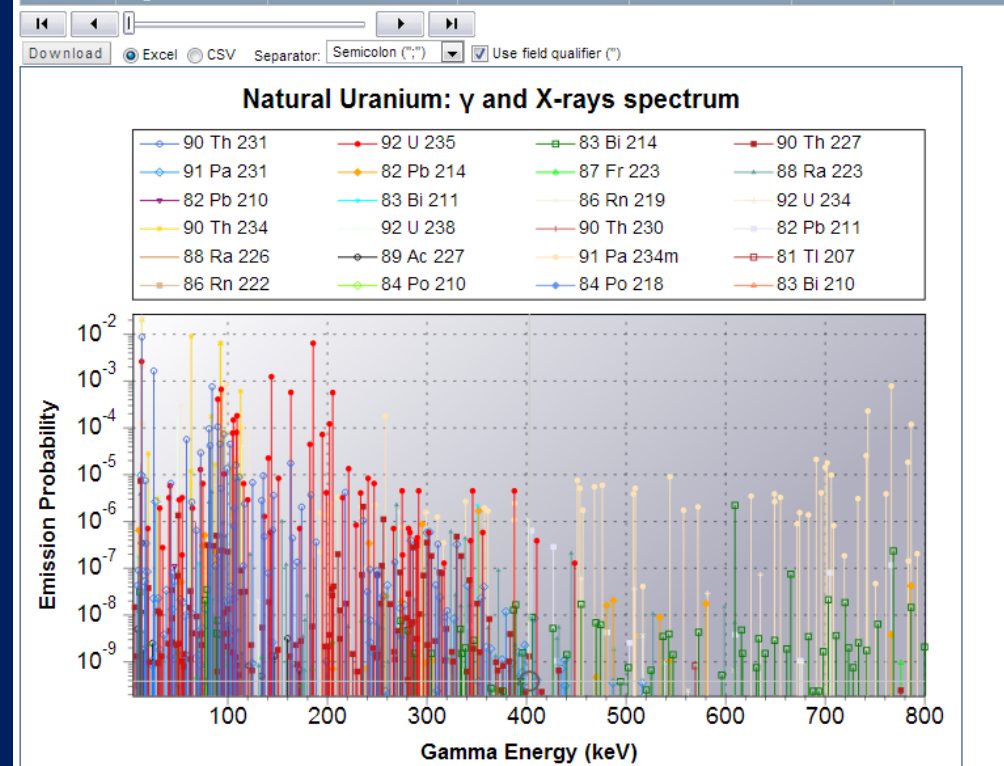
1.34E-02



Source Shield Detector

Source/detector distance (cm): 100

82 Pb 210	46.539	1.12E-07	0.00E+00	0.00E+00	1.00E+00	5.13E-02
82 Pb 210	3.228	8.46E-08	0.00E+00	0.00E+00	1.00E+00	1.47E+02
82 Pb 211	404.85	6.39E-07	0.00E+00	0.00E+00	1.00E+00	3.25E-02
82 Pb 211	831.85	6.34E-07	0.00E+00	0.00E+00	1.00E+00	3.16E-02
82 Pb 211	427	2.87E-07	0.00E+00	0.00E+00	1.00E+00	3.26E-02
82 Pb 211	766.35	1.18E-07	0.00E+00	0.00E+00	1.00E+00	3.19E-02
82 Pb 211	11.164	8.66E-08	0.00E+00	0.00E+00	1.00E+00	3.53E+00
82 Pb 211	704.5	8.02E-08	0.00E+00	0.00E+00	1.00E+00	3.21E-02
82 Pb 211	77.108	6.26E-08	0.00E+00	0.00E+00	1.00E+00	2.69E-02
82 Pb 211	74.815	3.73E-08	0.00E+00	0.00E+00	1.00E+00	2.76E-02
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Gamma Dosimetry & Shielding++

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Overview...

Biological Effects of Ionising Radiation

- Absorbed dose, Quality or Weighting Factor, Equivalent Dose

Attenuation of Gamma Radiation

- Calculation of the energy absorption, calculation of the equivalent dose rate, absorption in tissue, attenuation in shield materials, build-up factors

Nucleonica's Dosimetry & Shielding Module

The screenshot shows the Nucleonica web application interface for Dosimetry and Shielding++. The header includes the Nucleonica logo and the tagline "... web driven nuclear science". The navigation bar contains links for Applications, Data, Knowledge, My Preferences, Print, Networking, Nuclear Science, Help, and New Browser Tab. The main content area displays the "Dosimetry and Shielding++" module for "27 Cobalt". A small inset shows the Co60 isotope properties: 10.47 m and 5.27 y. The "Current Chart: Karlsruhe" is indicated. Below this, there are input fields for "Element" (Co) and "Mass" (60), and a "Mixture selector" button. A checkbox for "Include daughters" is also present. The main interface is divided into tabs: "Dosimetry and Shielding" (selected), "Dose rate/Thickness graph", "Options", and "Mixture details". The "Dosimetry and Shielding" tab shows a diagram of a radiation source (yellow radiation symbol) emitting rays through a shield (grey rectangle) to a detector (grey rectangle). The "Initial source strength" is set to "Activity(Bq)" with a value of "1E+06". The "Shielding material" is set to "Pb" with a thickness of "1 cm". The "Dose rate (µSv/h)" is calculated as "2.67E-01". The "Source/detector distance (cm)" is set to "100". The diagram labels the "Source", "Shield", and "Detector". At the bottom, there are "Start" and "Reset" buttons.

Hands on Exercises: Dosimetry & Shielding

1. What is the gamma dose rate from a 100 MBq source of Co-60 at 2m distance? (8.4 $\mu\text{Sv/h}$)
2. A ^{60}Co gamma ray irradiator containing a 2TBq source is directed at a 30 cm thick concrete wall. The wall is situated at 7.5 m from the source. What the exposure rate behind the wall? (1.08 mGy/h)
3. Regulation impose an exposure rate outside the room of 7.5 $\mu\text{Sv/h}$ max. What thickness of wall would we then need? (75 cm)
4. We want to restrict the exposure rate inside the room (@1m from the irradiator) to 10 $\mu\text{Sv/h}$ using lead. Calculate the required thickness. (20 cm)
5. $^{99\text{m}}\text{Tc}$ is used in radioactive isotope medical tests, for example as a radioactive tracer that medical equipment can detect in the body. It is well suited to the role because it emits readily detectable 140 keV gamma rays, and it has a short half-life of 6.01 hours (meaning it has almost completely decayed to ^{99}Tc in 24 hours). A patient is injected 30 mCi of $^{99\text{m}}\text{Tc}$. He is considered as an unshielded source during the time there is radioactivity in his body. Thus the staff is exposed to radiation. What is the equivalent dose rate that a staff member can be exposed to? (medium is tissue, 1 cm thick @1 m distance) (16.5 $\mu\text{Sv/h}$)

6. What is the gamma dose rate from 1 MBq freshly separated pure Cs-137 at 1m?
($2.36\text{E-}7 \mu\text{Sv/h}$)

- Why is this so different to the ambient dose rate $h_{10} = 9.2\text{E-}2 \mu\text{Sv/h}$?
(daughter Ba137m has not been considered)
- Redo the calculation for Cs-137 and include the daughters. What is now the gamma dose rate at 1m? ($8.46\text{E-}2 \mu\text{Sv/h}$)

7. In question 6, the main gamma dose rate contribution arises from the Ba137m daughter of Cs-137. We are interested in comparing the gamma dose to the beta dose rate from Cs137:

- The beta particle energy from the decay of Cs-137 is 514 keV. Use the Range & Stopping Power module to calculate the range of this beta particle in tissue? (1.98 mm)
- Use the Virtual Cloud Chamber to show that 2 mm tissue is sufficient to block all beta particles (try using 1 mm, 1.5 mm, 2 mm). Use the following settings:
Medium = Vacuum, Shield = Soft Tissue (ICRP), Shield thickness = 2 mm, Particle: electrons, Energy = 514 keV, No. particles = 100, Source diameter = 0 (point source), Magnetic field = 0.01 tesla, Source to shield distance = 10 cm, Source to detector = 20 cm
- Compare the h_{10} and h_{07} values. What do these quantities indicate?
[$h_{10}=9.2\text{E-}2 \mu\text{Sv/h}$ (mainly gamma dose rate), $h_{07} = 20 \mu\text{Sv/h}$ (mainly β dose rate)]

